What are the drivers of brightening over the Western North Atlantic Ocean?

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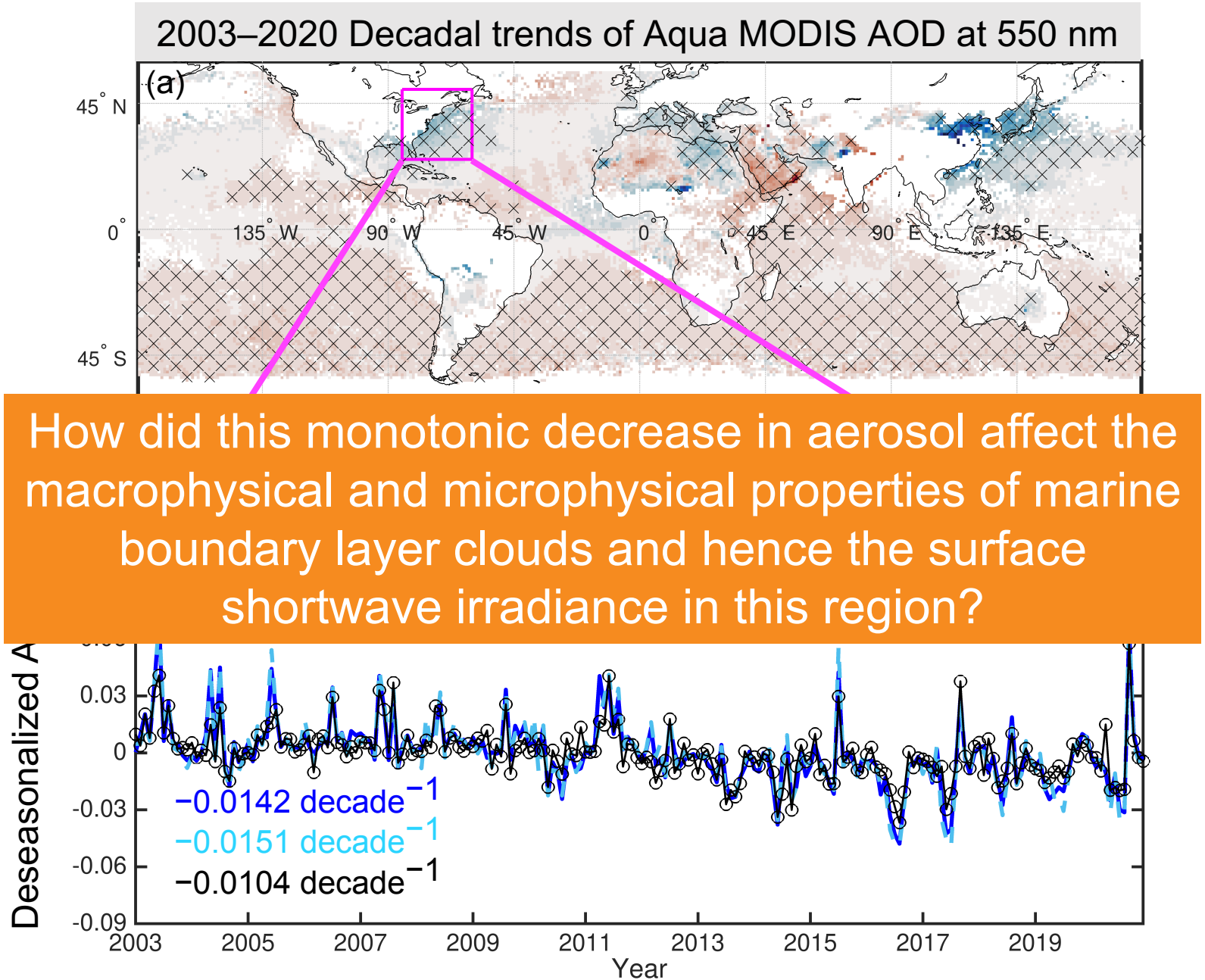
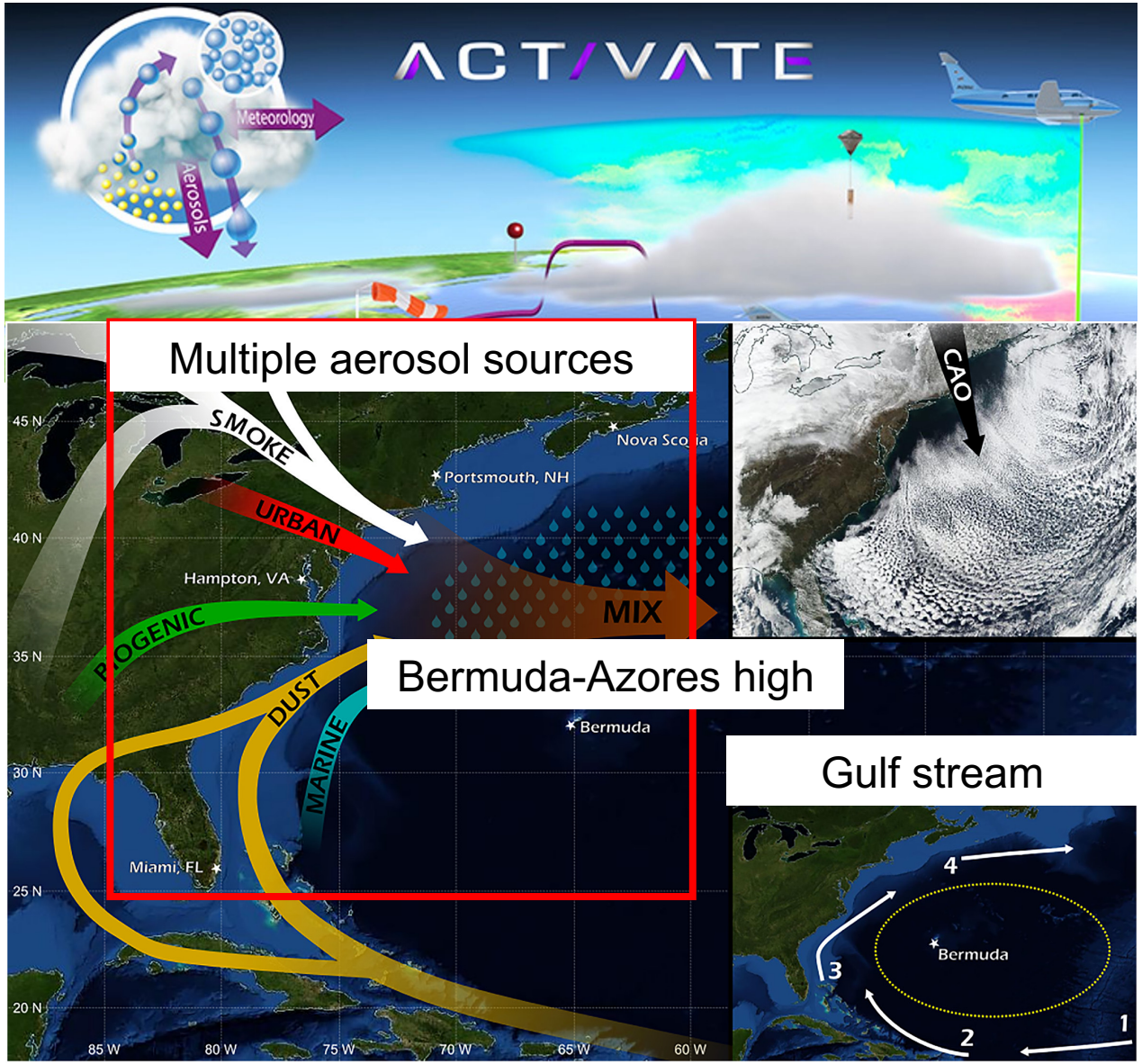
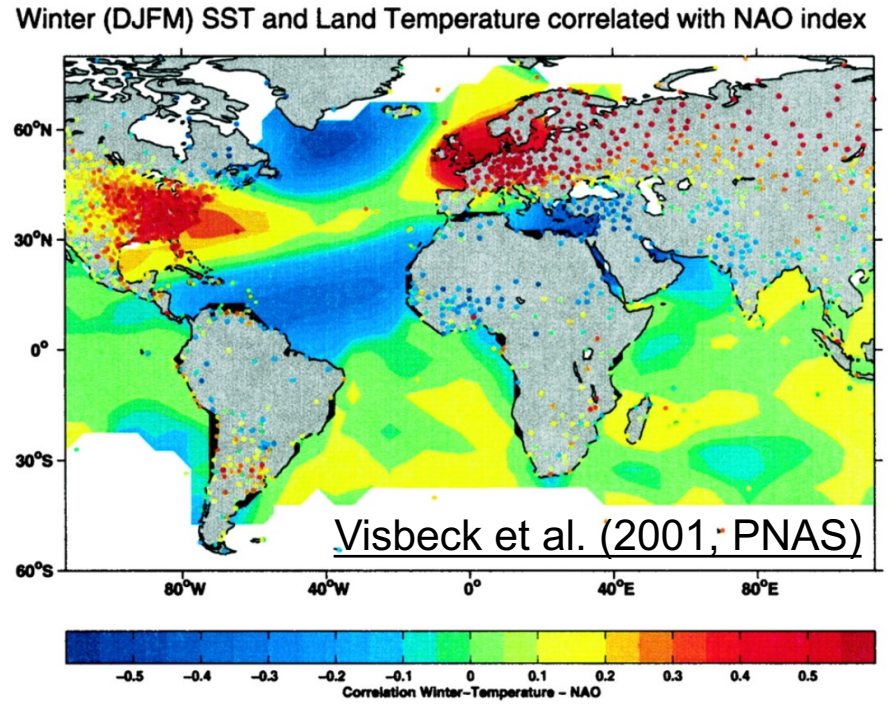
A continuous & robust decrease in aerosol optical depth



Over the WNAO, atmospheric and oceanic phenomena of different spatiotemporal scales coexist



- Aerosol Cloud meTeorology Interactions oVer the western ATlantic Experiment (Sooroshian et al., 2019)
- Goal of characterizing the relationships between aerosol and microphysical and macrophysical properties of marine boundary layer clouds under different meteorological conditions over the downwind of the U.S.



Approach

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- Decadal trend analysis of 18-year (2003–2020) monthly data
- Mann-Kendall test for statistically significant trends

Dataset and variables

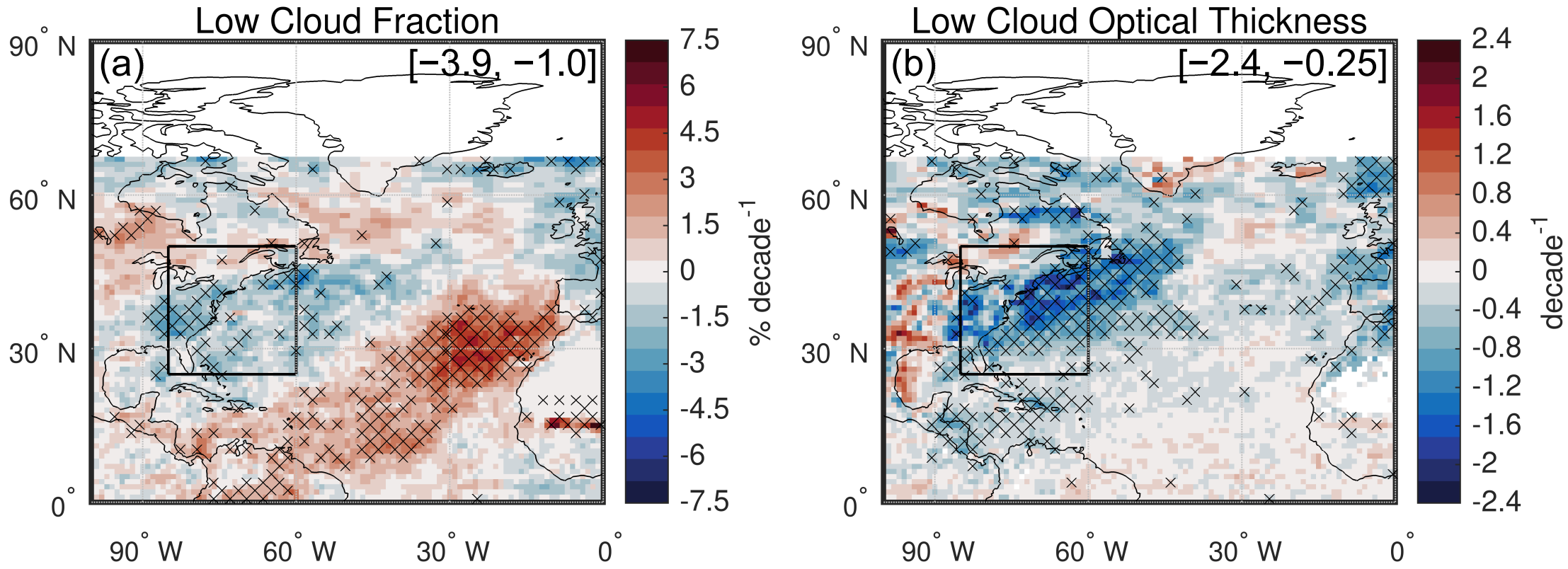
Aerosol, clouds, and radiation

- CERES EBAF Ed4.1 surface shortwave radiation flux
- Aqua MODIS aerosol optical depth at 550 nm
- CERES MODIS SSF Level 3 low cloud (heights below 700 hPa) properties

Meteorology

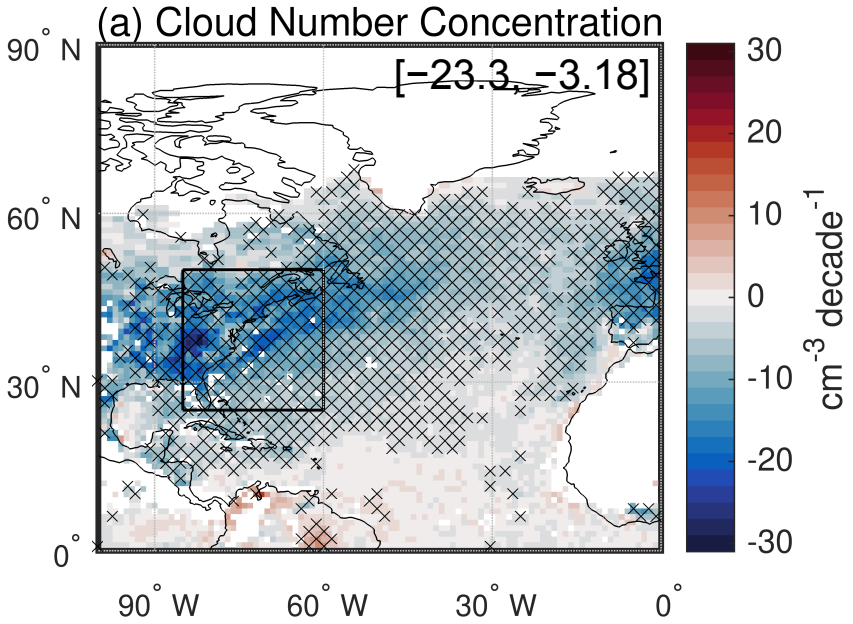
- OISST v2 sea surface temperature
- RSS total precipitable water
- ERA-5 mean sea level pressure, 500-hPa geopotential height, and 10-m wind
- NOAA CPC North Atlantic Oscillation index

Changes in low cloud macrophysical properties



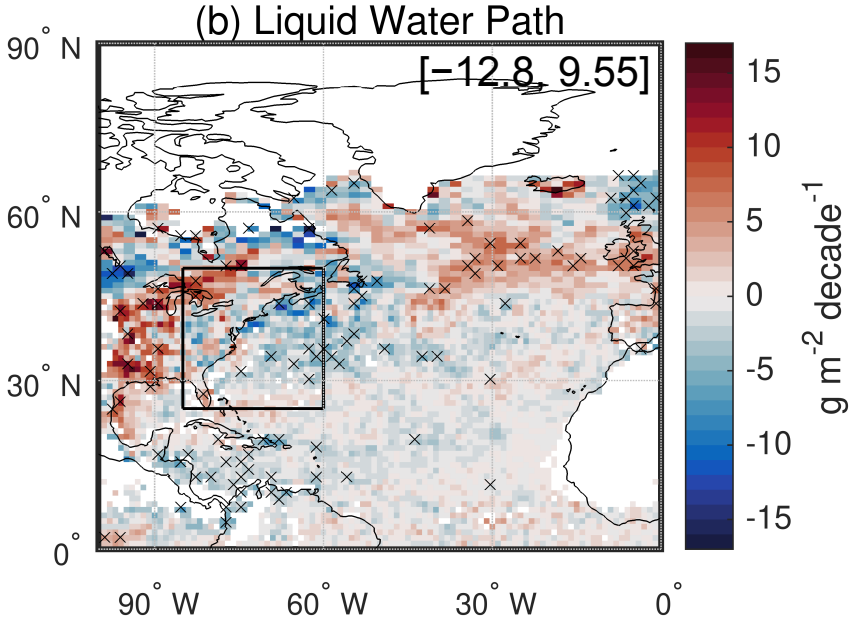
Cloud fraction and optical thickness as the primary drivers of the cloud radiative effect

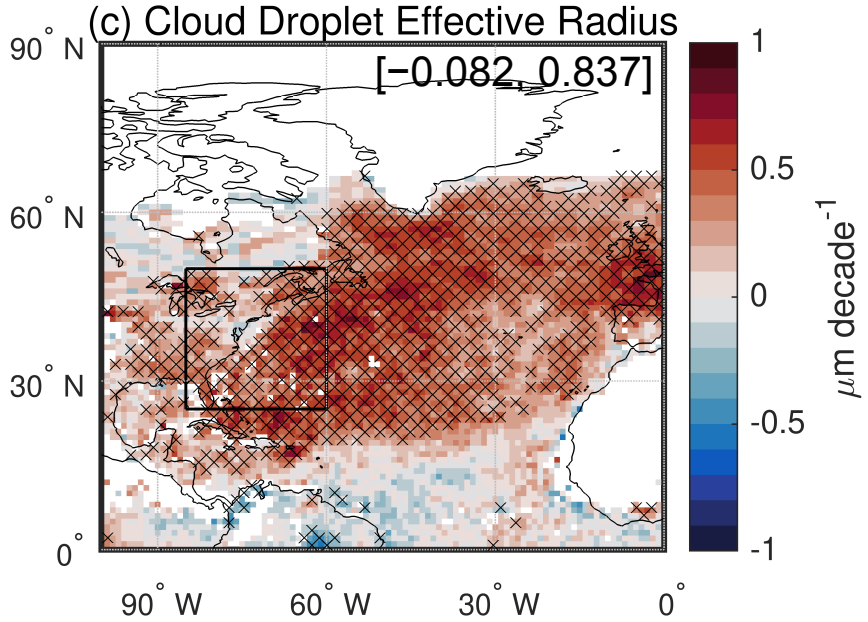
Changes in low cloud microphysical properties



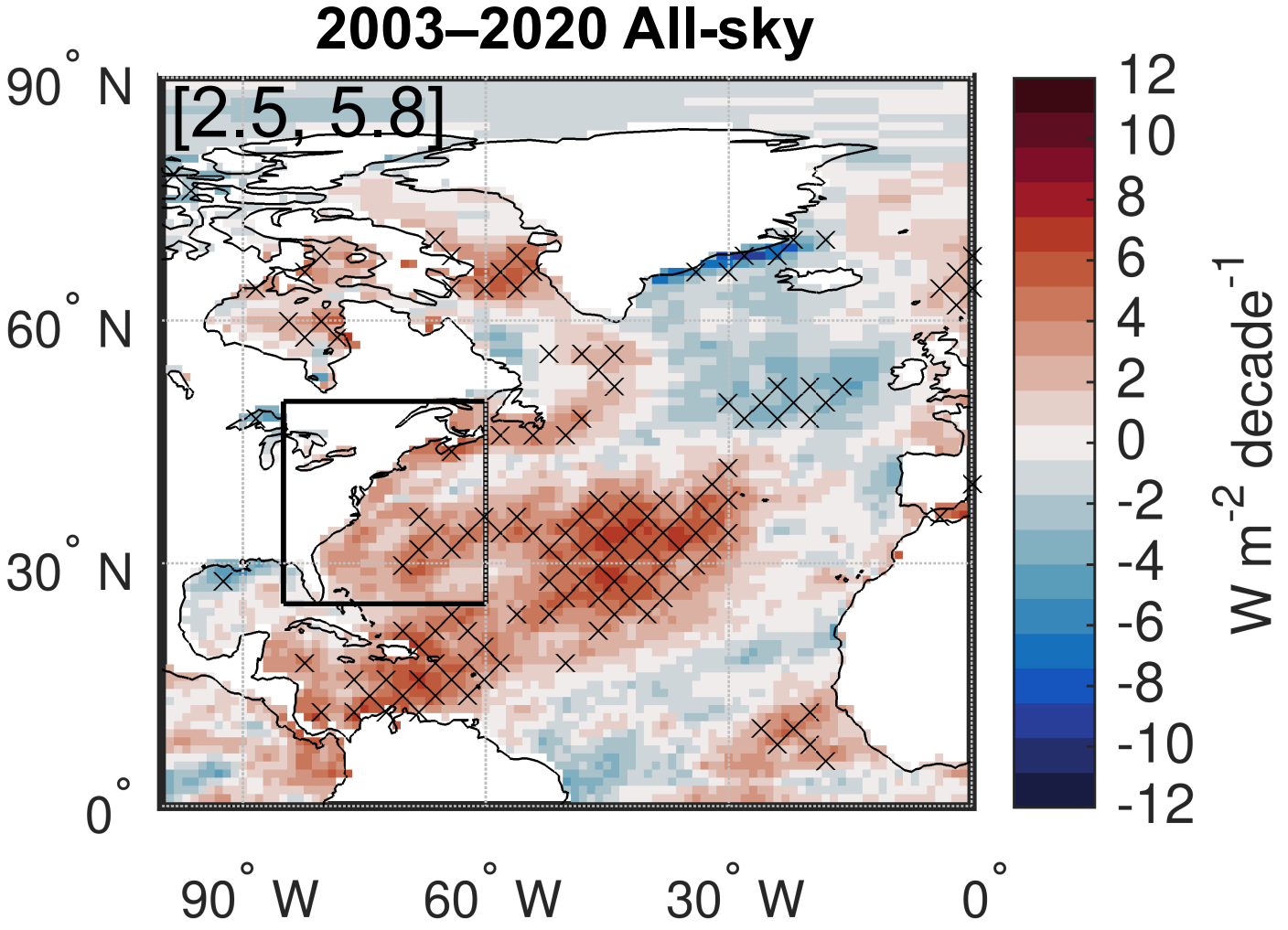
- Pervasive trends in droplet effective radius and number concentration with limited changes in liquid water path

- Significant changes in cloud mircophysics:
  - *absent* from May–August when the magnitude of decreasing trends in aerosol optical depth is greatest
  - *present* from October-March when limited significant trends in aerosol optical depth is observed





Pervasive changes in cloud microphysics are not reflected in the down welling surface solar irradiance

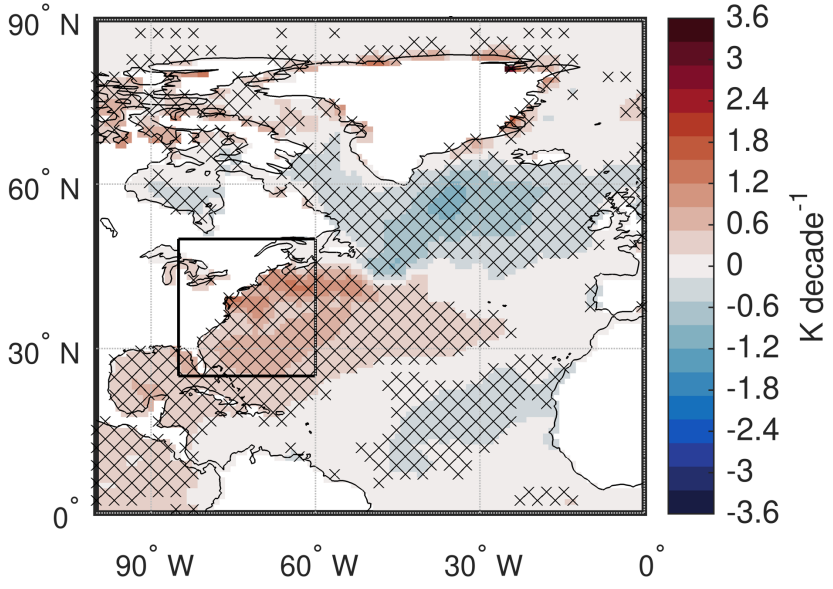


- Accounting for seasonality (not shown), this indication of negative Twomey effect is not reflected in the trends in surface shortwave irradiance due to many complex factors operating on the radiation balance in this region

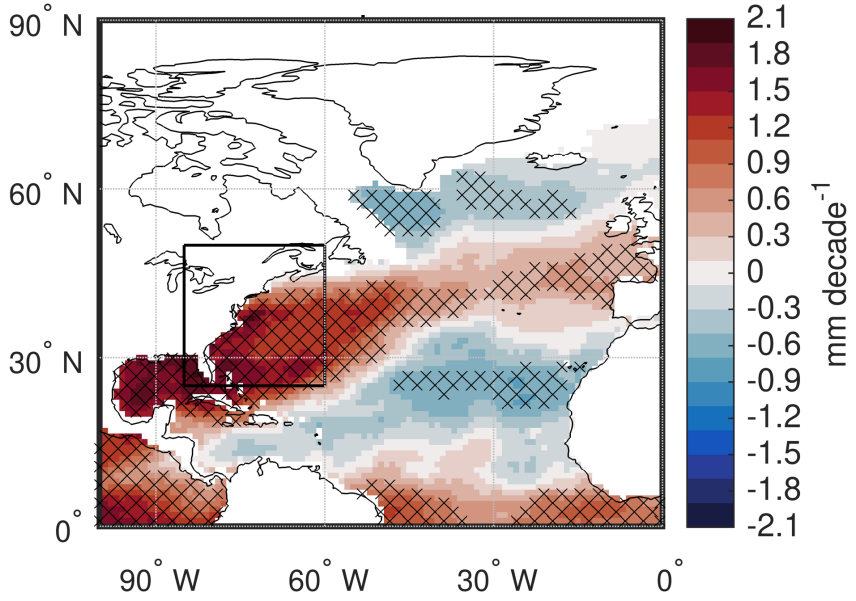
Changes in meteorological fields

- Tripole pattern
- Midlatitude SST warming, subtropical and subpolar cooling
- Corresponding increase and decrease in TPW
- Changes in the base state

Trends in SST



Trends in TPW



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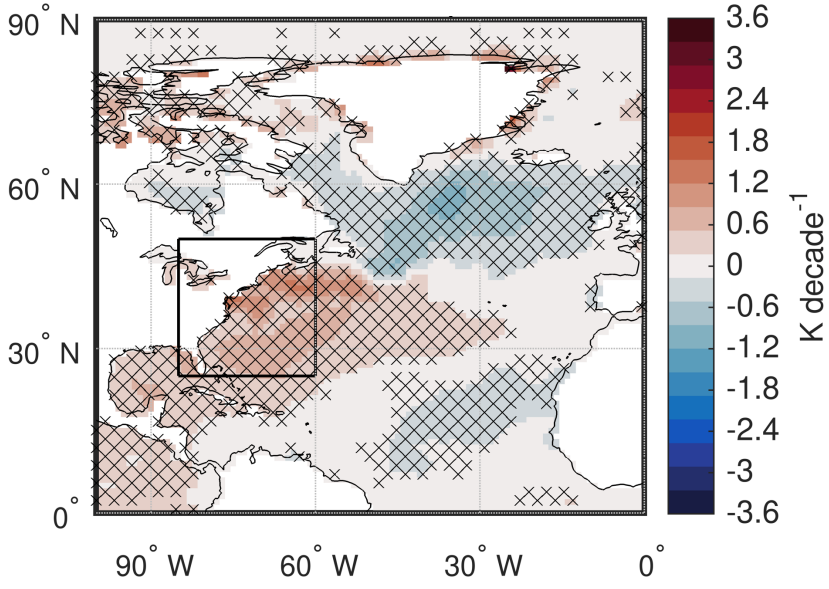
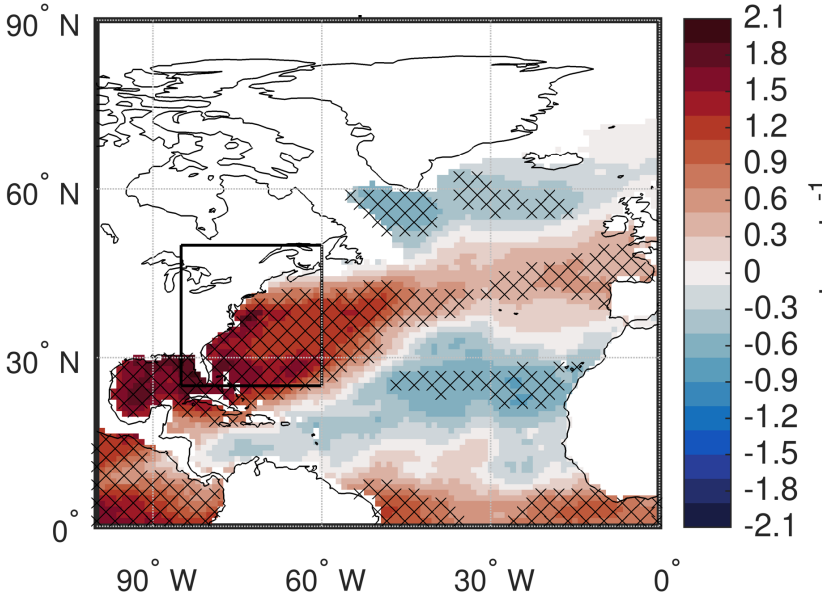
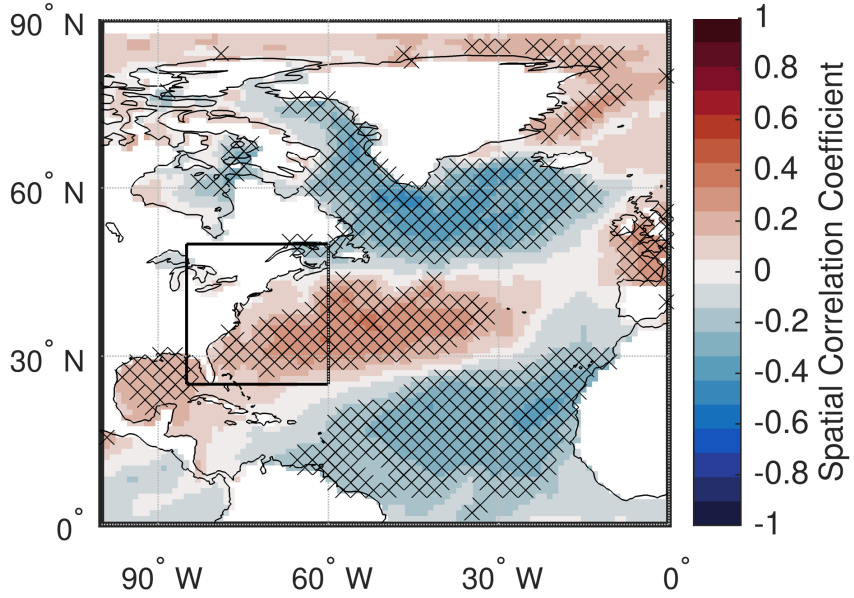


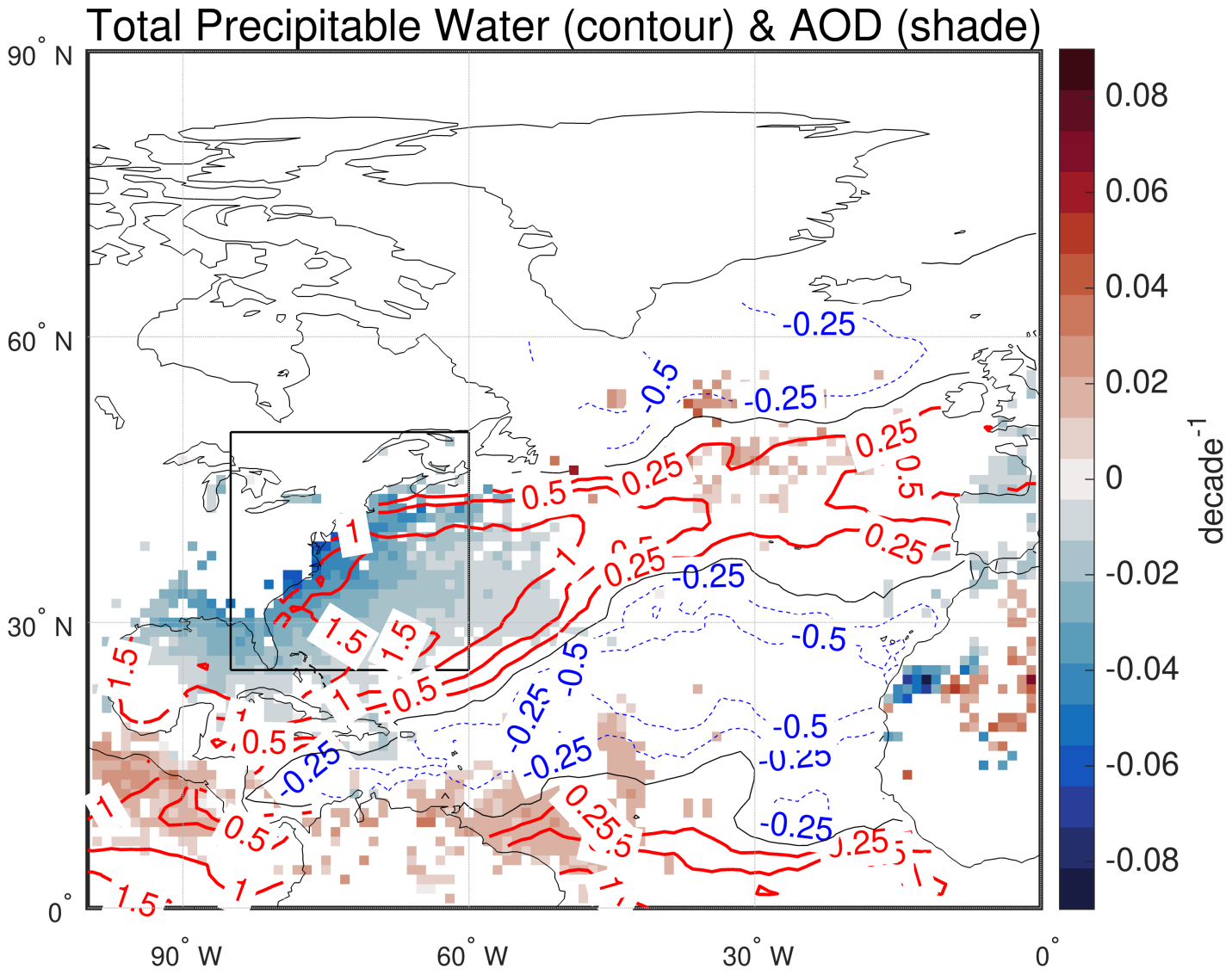
Trends in TPW

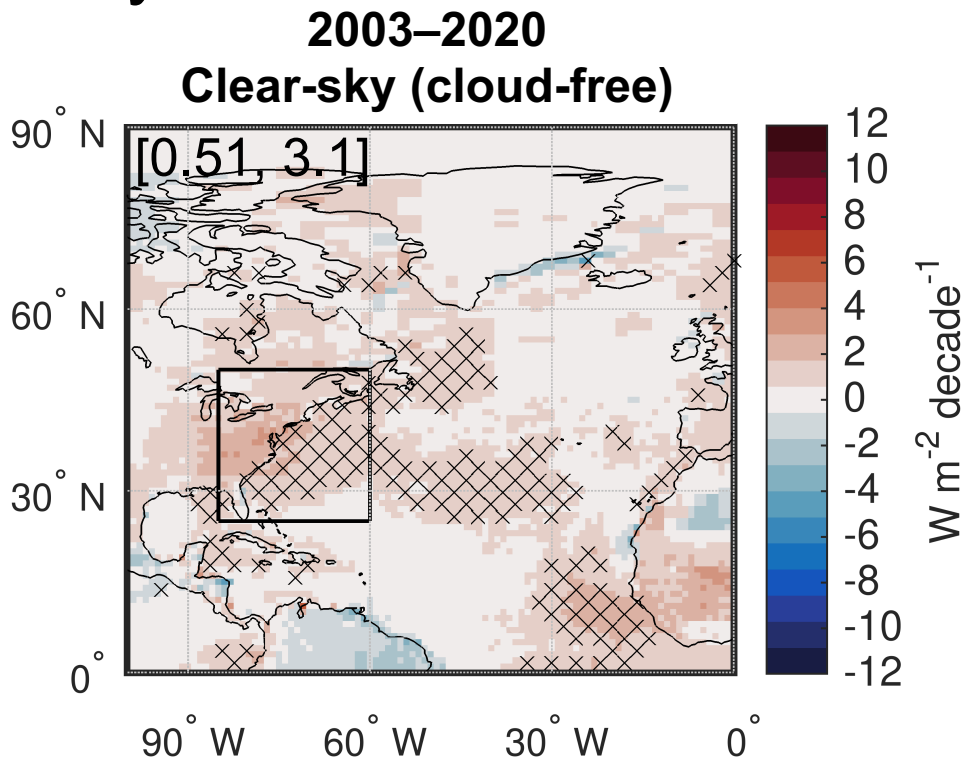


Correlation between NAO index & SST



Opposite radiative effect between decreasing AOD & increasing total precipitable water in clear sky

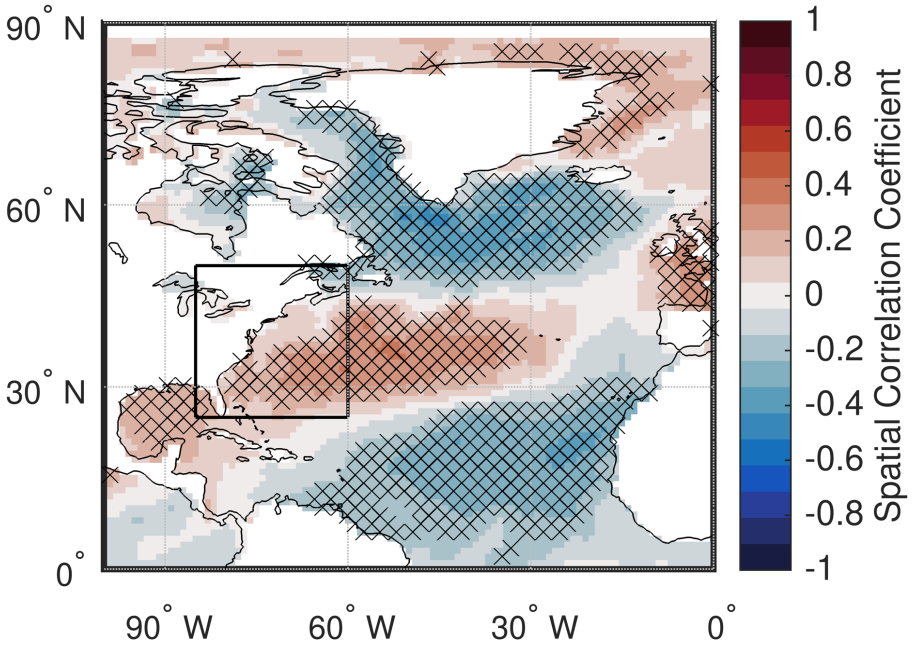




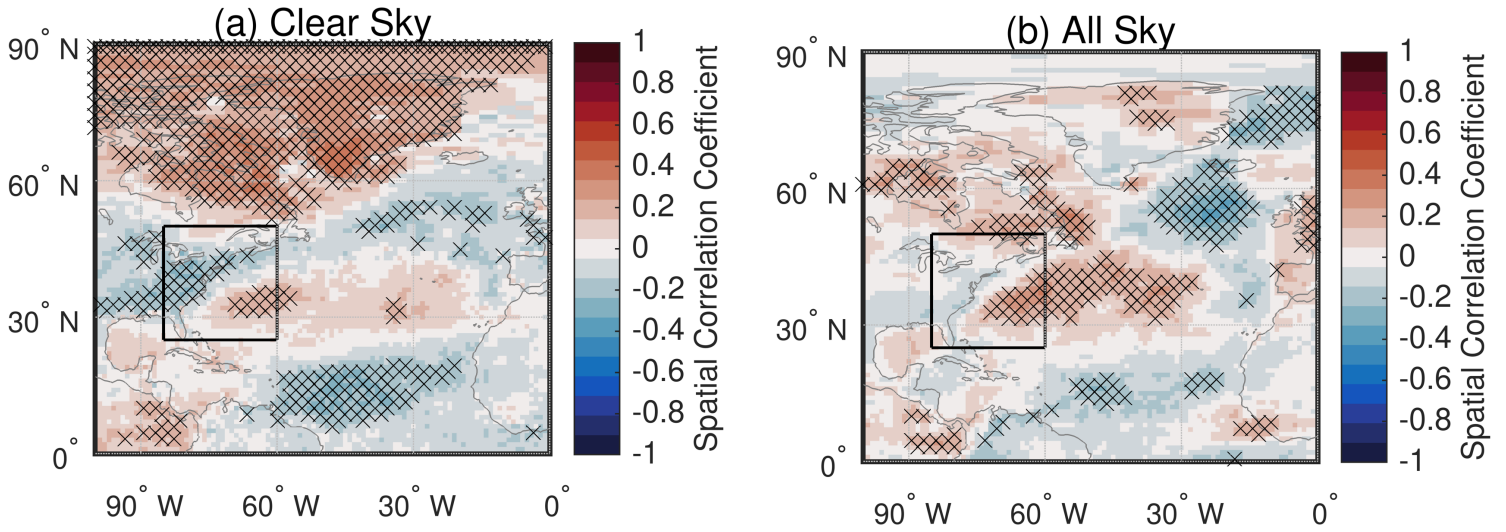
- Brightening from decreasing AOD
- Dimming from increasing TPW via shortwave absorption
- **Net brightening**

Tripolar patterns in NAO-surface solar irradiance correlation

Correlation between NAO & SST



Correlation between NAO index surface irradiance



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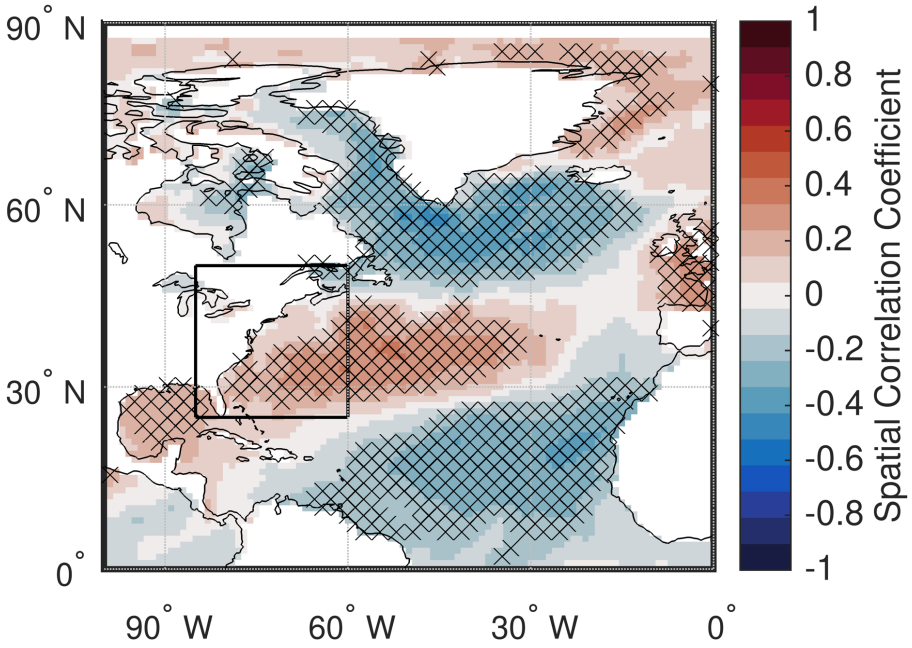

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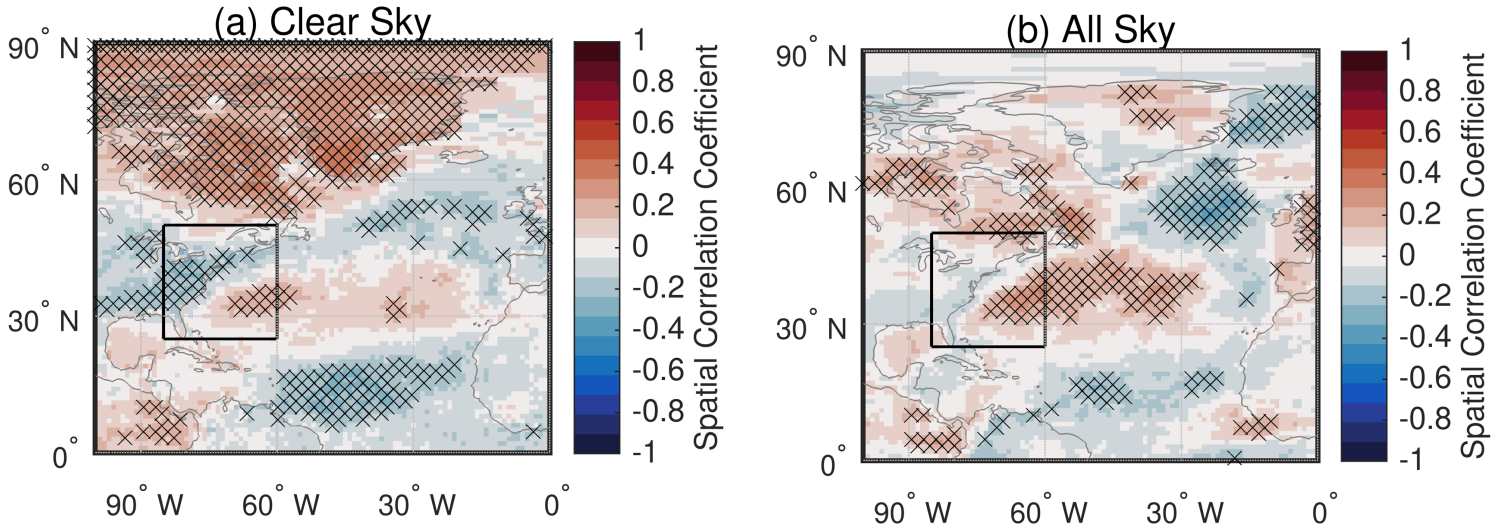
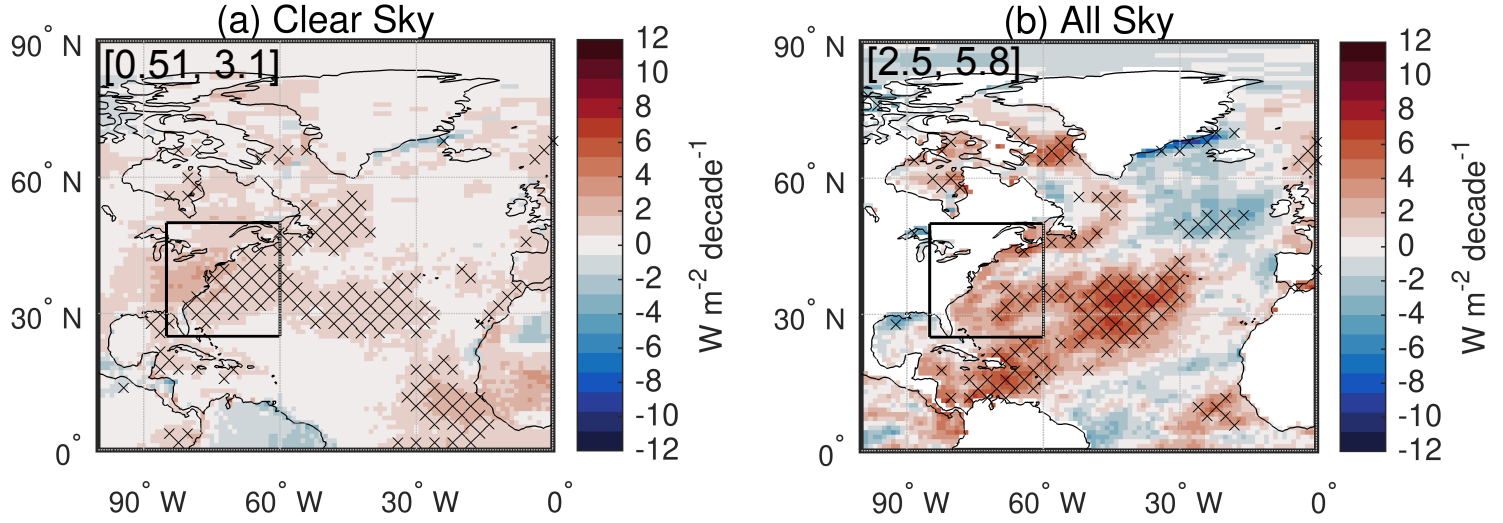
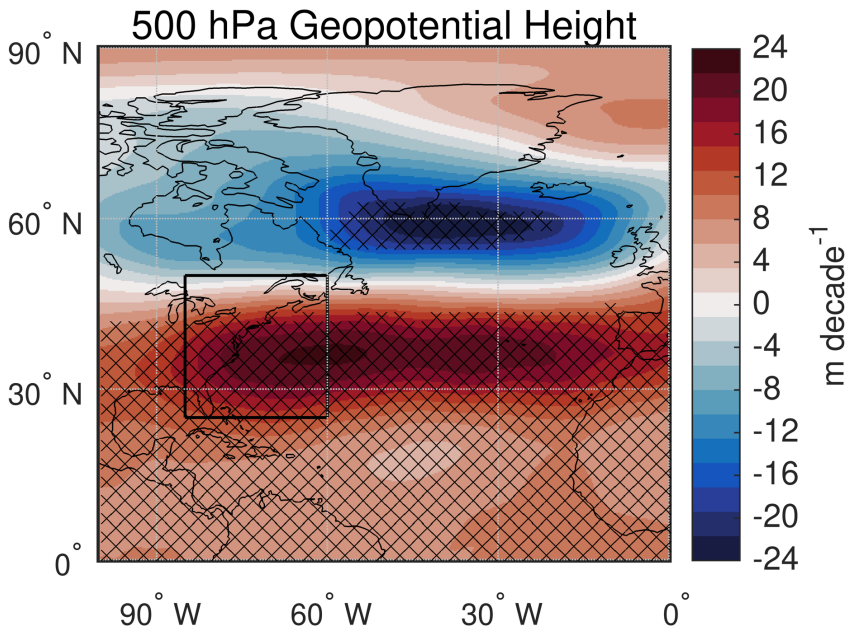
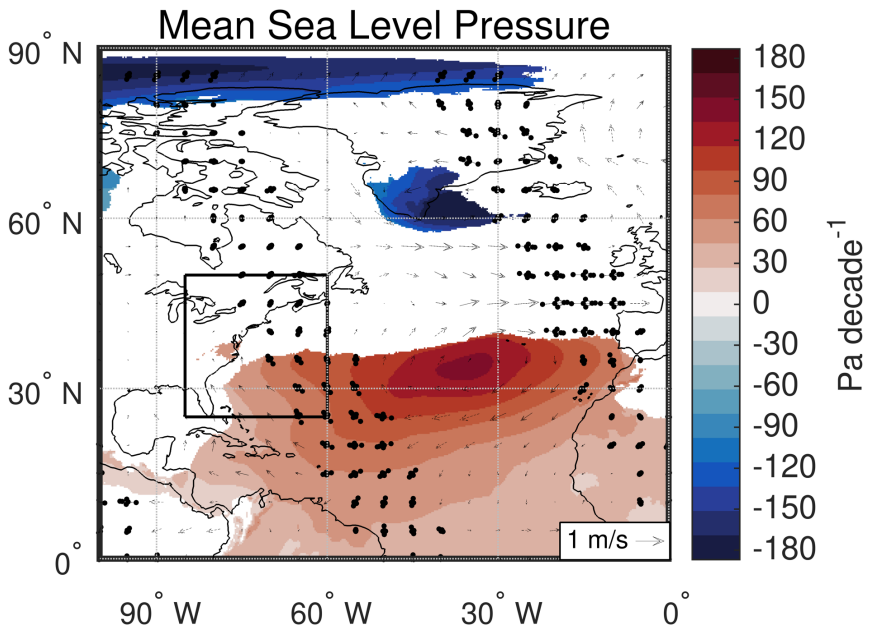


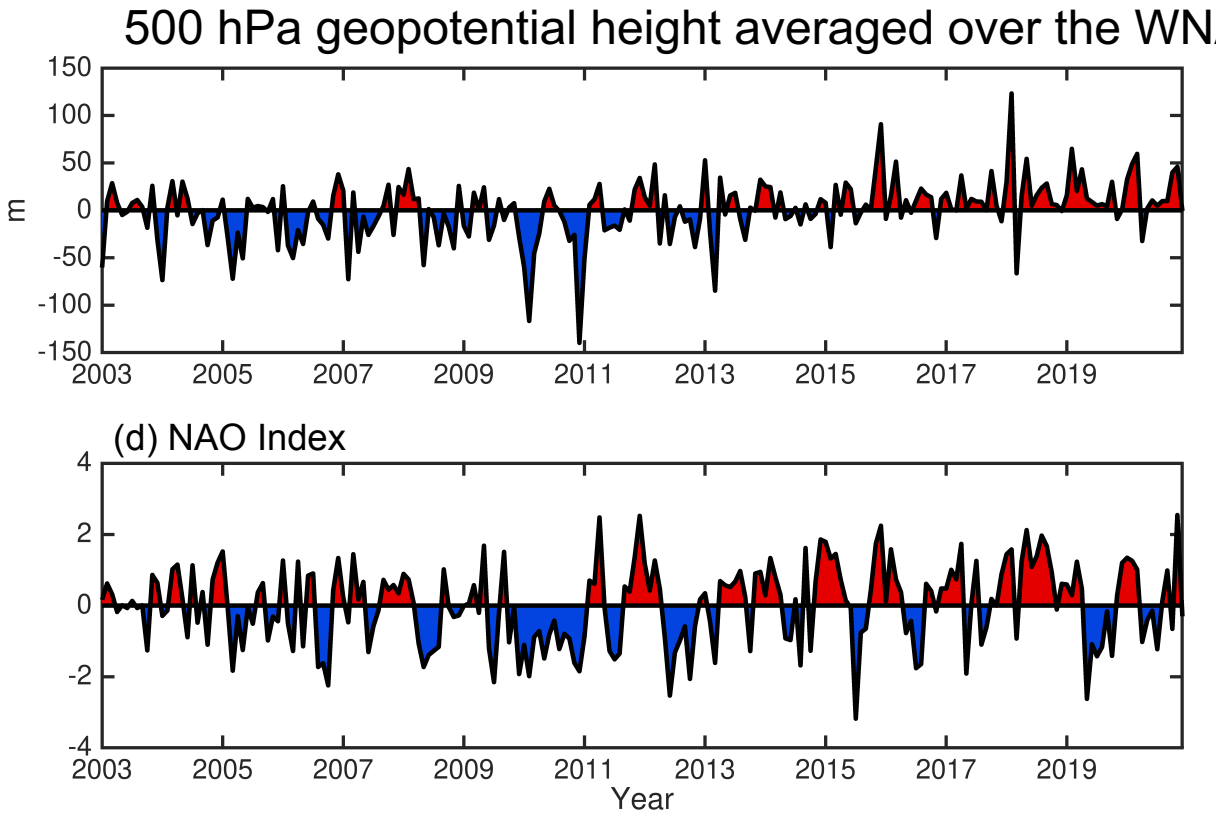
Decadal trends of surface shortwave irradiance



Has the North Atlantic Oscillation changed?





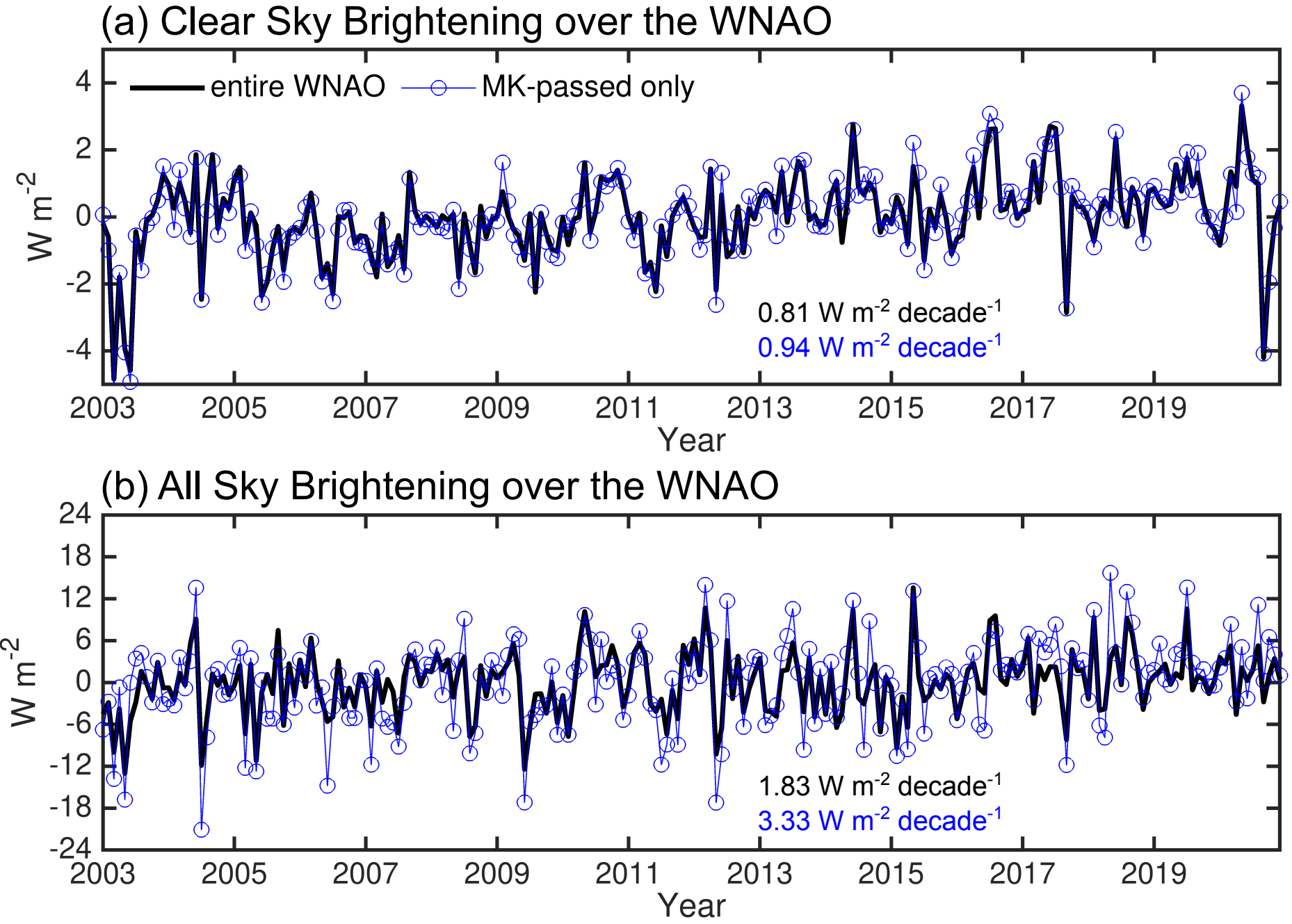


- Stronger Bermuda-Azores high
- Stronger subpolar low
- Greater pressure gradient
- Implying changes in North Atlantic Oscillation
- Likely bounds the spatial extent of AOD trends

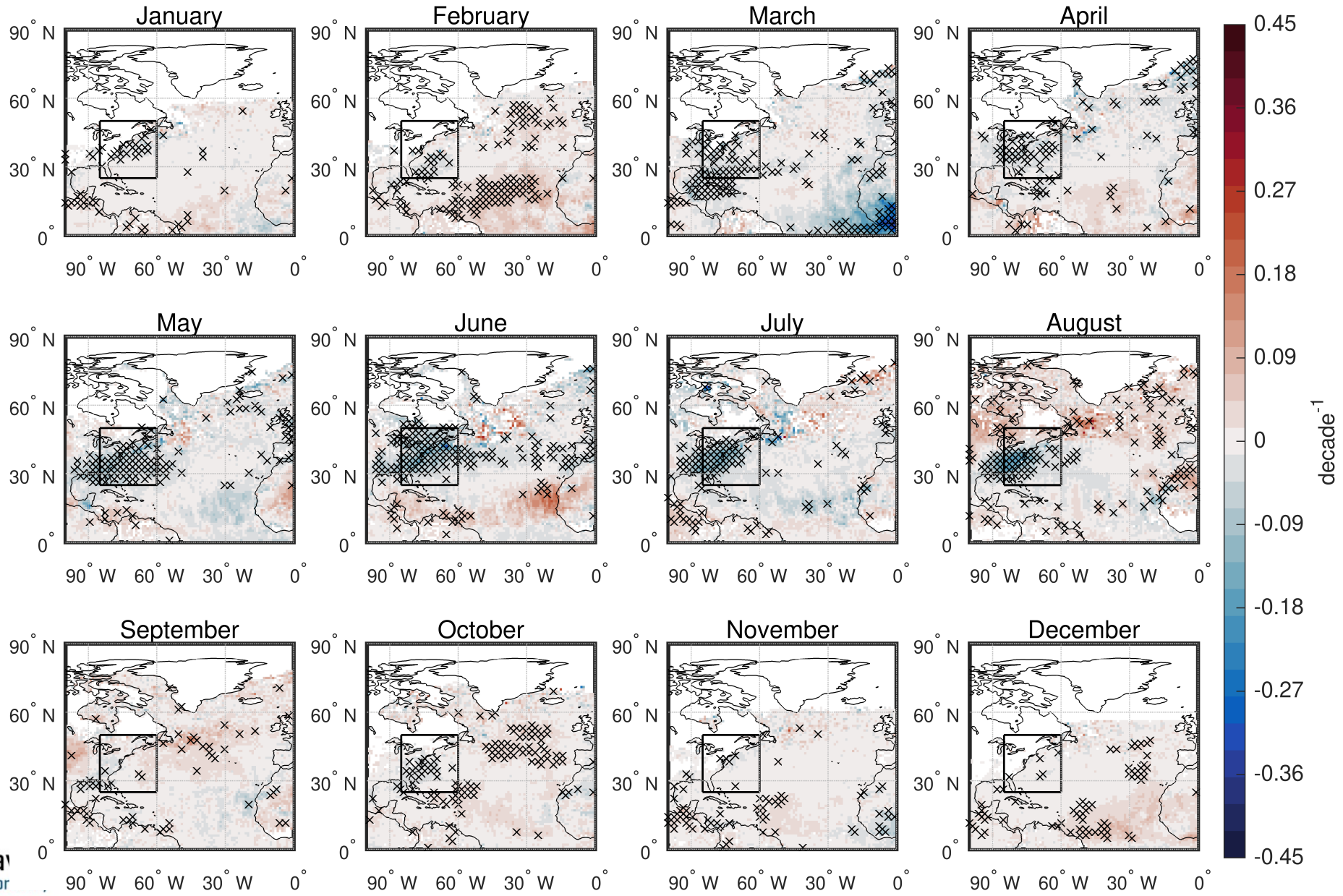
Summary

1. How have aerosol-cloud interactions influenced the surface radiation budget in the Western North Atlantic over the 18-year satellite data record?
   - Despite a robust signal in cloud microphysical properties over the WNAO (increasing $\mathbf{r_{eff}}$/decreasing $\mathbf{N_d}$ with decreasing AOD), an expected increase in the surface shortwave radiation is not found.

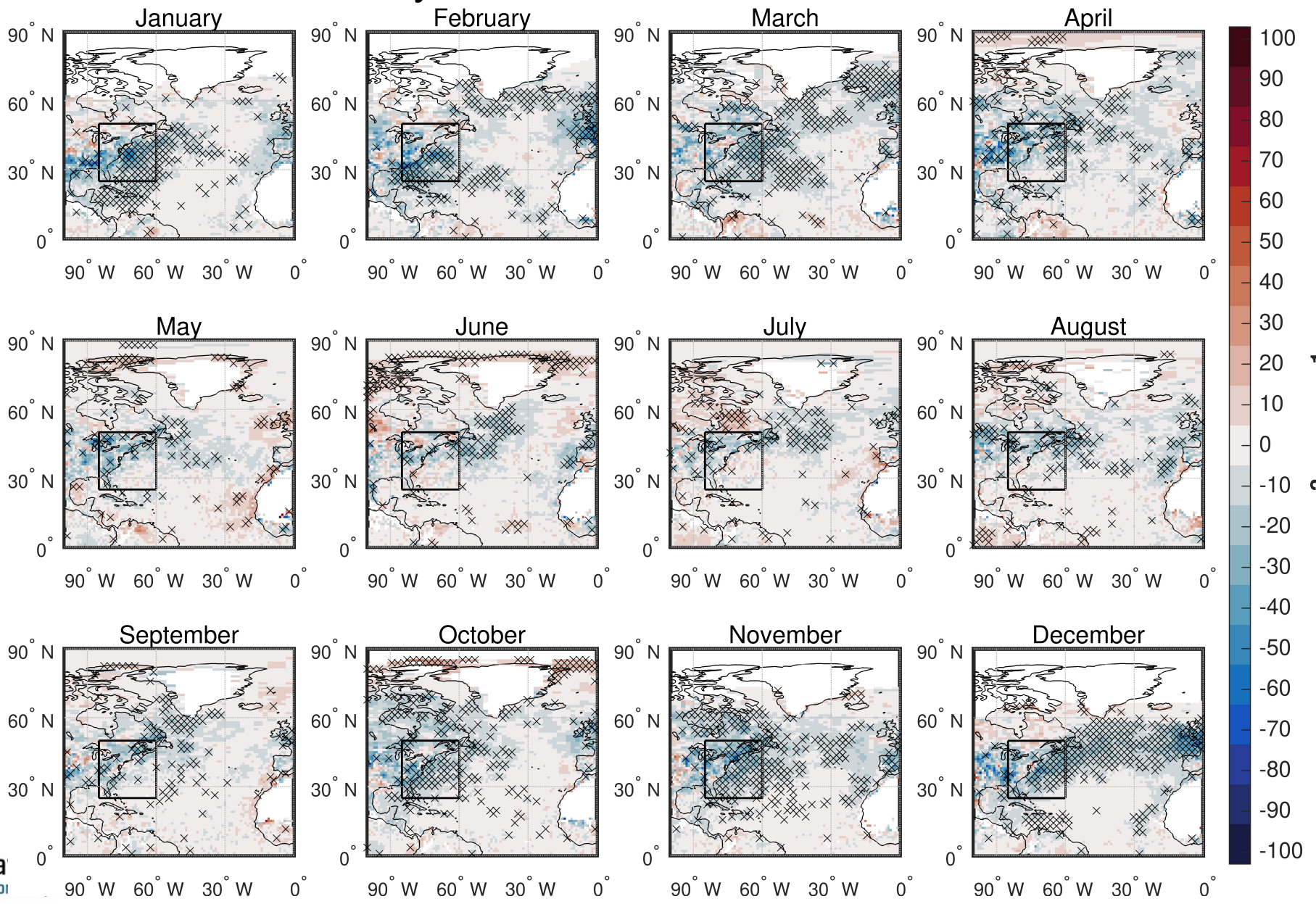
2. Can we use the different spatiotemporal patterns in aerosol and meteorological variability to characterize the contributions of aerosol indirect effects and natural variability of the climate system to changes in the radiation budget via the cloud radiative effect?
   - Changes in water vapor which are shown to impact the clear-sky surface shortwave radiation may also impact cloud radiative properties
   - Changes in SST and water vapor exhibit a tripole pattern that is positively correlated to the NAO and may impact cloud properties through natural variability
   - While not shown here, statistically significant changes in mid- and high-level clouds were found that may compensate for aerosol-induced changes in low cloud.

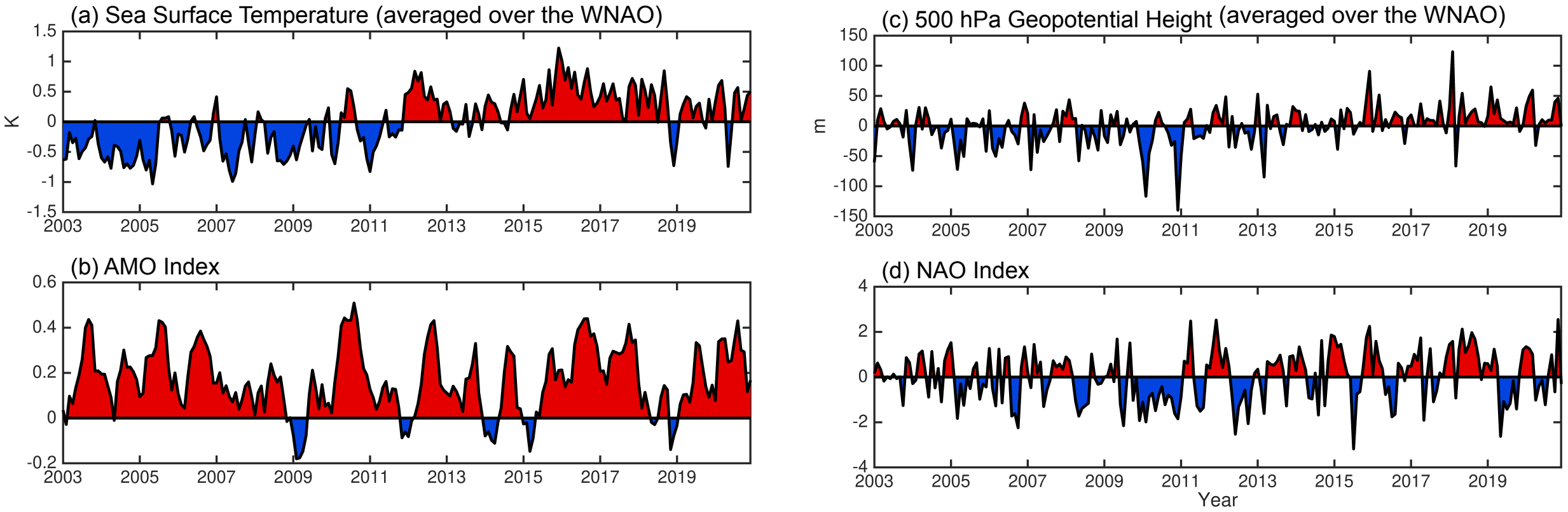

(a) Clear Sky Brightening over the WNAO
entire WNAO
MK-passed only
W m-2
4
2
0
-2
-4
2003
2005
2007
2009
2011
2013
2015
2017
2019
Year
0.81 W m-2 decade-1
0.94 W m-2 decade-1
(b) All Sky Brightening over the WNAO
W m-2
24
18
12
6
0
-6
-12
-18
-24
2003
2005
2007
2009
2011
2013
2015
2017
2019
Year
1.83 W m-2 decade-1
3.33 W m-2 decade-1

Monthly Aqua-MODIS AOD Decadal Trends



Monthly Low Cloud Number Concentration




(a) Sea Surface Temperature (averaged over the WNAO)
K
1.5
1
0.5
0
-0.5
-1
-1.5
2003
2005
2007
2009
2011
2013
2015
2017
2019
(b) AMO Index
0.6
0.4
0.2
0
-0.2
(c) 500 hPa Geopotential Height (averaged over the WNAO)
m
150
100
50
0
-50
-100
-150
(d) NAO Index
4
2
0
-2
-4
Year